Evidence that clouds of keV hydrogen ion clusters bounce elastically from a solid surface

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The behavior of hydrogen ion clusters is tested by an inject/hold/extract technique in a Penning-Malmberg trap. The timing pattern of the extraction signals is consistent with the clusters bouncing elastically from a detector several times. The ion clusters behave more like an elastic fluid than a beam of ions.

A Penning Malmberg trap, designed to be a portable container for antiprotons[1], is tested using normal matter to evaluate storage quantities and lifetimes. The design is based on several other traps described[2,3] in the literature. The trap consists of a series of 6 cm diameter cylindrical electrodes comprising the trap structure centered in a 4 T magnetic field. A set of similarly sized lens extending outside the magnetic field focus extracted ions onto a micro-channel plate (MCP) detector. Figure 1 illustrates the electric potential along the centerline of the Penning-Malmberg trap with the positions of electrodes and extraction lens; the ion beam is terminated at the MCP located at an axial position of z=64cm.
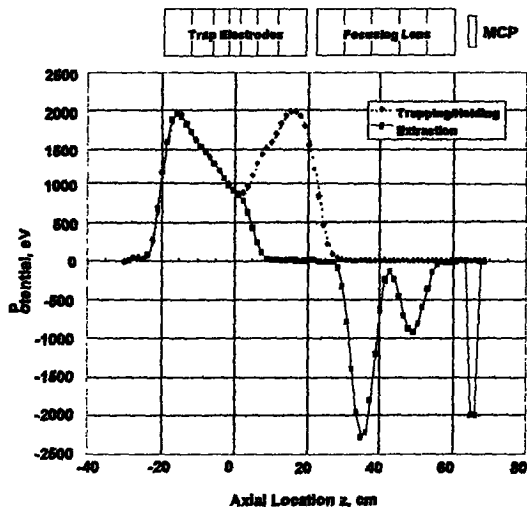

FIG. 1. Potentials created by electrodes.

With the trap in the closed configuration, an electron beam initiates a Penning discharge in the trap, with trapped electrons and ions creating secondary ionization. Initially the pressure is 7 pTorr. While the electron beam is firing, the pressure rises to 30 pTorr. After 15 seconds the pressure returns to normal, leaving a cloud of ions in the central potential well.

After holding for 3 minutes, the ions are extracted, by switching downstream electrodes to ground in approximately 100 nsec. During the hold and extraction periods, trap electrodes, focusing lens and the MCP are energized as illustrated in figure 1. A typical set of signals from the MCP is shown in figure 2.
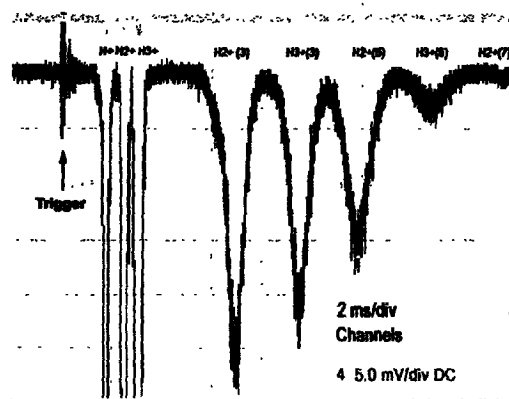

FIG. 2. Typical MCP signals recorded on LeCroy LC544DL Oscilloscope.

The timing of the signals corresponds to the pattern: $1, \sqrt{2}$, $\sqrt{3}$, $3*\sqrt{2}$, $3*\sqrt{3}$, $5*\sqrt{2}$, $5*\sqrt{3}$, and $7*\sqrt{2}$. This timing pattern corresponds to prompt H^+, H_2^+ and H_3^+ ion clusters, followed by H_2^+ ions traveling back and forth three times between the trap and MCP, and H_3^+ ions bouncing twice. No evidence for the multiples 3,5,7 is observed, implying that H^+ ions do not bounce efficiently. The signals recorded by the MCP correspond to approximately 50 thousand ions in each of the first 6 peaks.

The relative sizes of the delayed signals imply that the bounce mechanism is efficient, in that a major fraction of the ions are reflected elastically. For comparison, backscattering[4] of individual ions is an inefficient process, with only $2\pm1\%$ of H or He ions backscattering with enough energy to escape from the -2000 eV potential well around the MCP. The time-of-flight distribution of backscattered ions would include a tail tens of μsec long, unlike the sharp peaks observed in figure 2. The data of figure 2 are inconsistent with a model based on the behavior of individual ions impinging on a solid surface.

Because of emittance growth in the fringing magnetic field, only ions originating within a 0.25 cm radius of the trap axial centerline can be transported to the 1.25 cm radius of the active region of the MCP. The possibility that most of the reflection occurs on the smooth annular stainless steel housing (width of 1.0 cm) which surrounds the active region cannot be ruled out.

Several variations have been investigated. With higher trap potentials, the timing pattern is tighter, as expected for faster ions travelling over the 64 cm path between the center of the trap and the MCP. When the trap was closed 7 μsec after an extraction, the late signals were more tightly bunched. The timing was consistent with ions reflecting back and forth over the shortened distance between the MCP and the downstream end of the trap. These observations are inconsistent with alternative explanations, such as switching transients and heavier ion clusters.

In conclusion, the interpretation of the data is that a cloud of H_2^+ or H_3^+ ions behaves more like an elastic fluid than a beam of ions, when extracted from a Penning Malmberg trap, accelerated to 3 keV and collided with a solid detector surface.

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